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IMPEDANCES OF CORRUGATED BEAM PIPE IN THE SSC INTERSECTION REGIONS

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ABSTRACT

In order to allow for measurement of forward particles, the beam pipe in the interaction region is made corrugated. The impedance of such a section of beam pipe is examined

INTRODUCTION

Forward detectors are required to study systems of mass 1.6 TeV (or more) which have essentially the full SSC forward momentum. In order to have full particle identification, tracking, momentum measurement, muon measurement, μ-vertex detection and calorimetry, prior experience at the ISR and planning for the SPS-collider suggest a special configuration for the vacuum pipe at the interaction region. The design[1], as shown in Fig. 1, consists of a series of 4 conical structures with thin stainless steel windows at distances 1, 20, and 100 meters so that spectrometers can be placed behind them. However, such a configuration includes steps which will contribute to extra impedances. The purpose of this paper is to estimate these impedances.

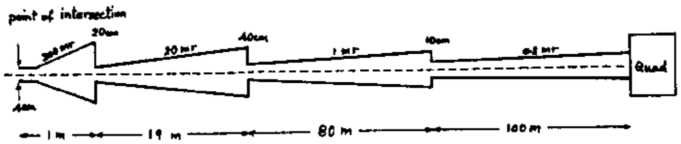

Fig. 1. The shape of the beam pipe near intersection point. The drawing is not to scale.

LONGITUDINAL IMPEDANCE OF ONE CONICAL SECTION

Each conical section is a step at low frequencies and forms a cavity at high frequencies so that resonances will occur. It is not possible to study the whole section, 200 m, at a time; so we concentrate on the first conical section and try to infer the result for the rest.

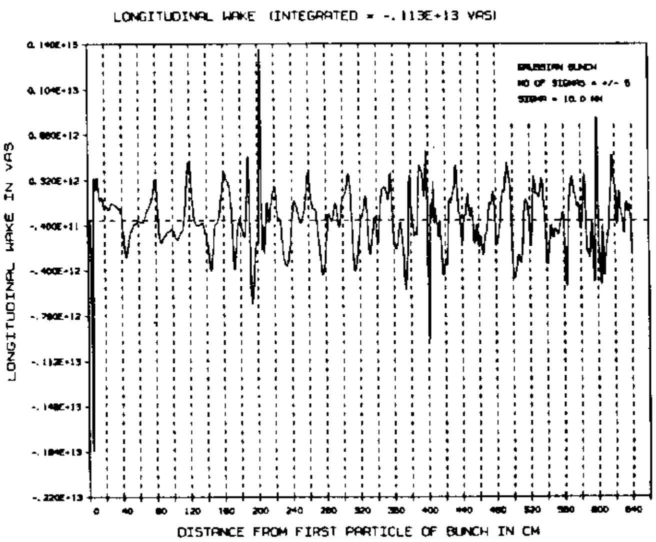

Fig. 2. Longitudinal wake of the first conical section.

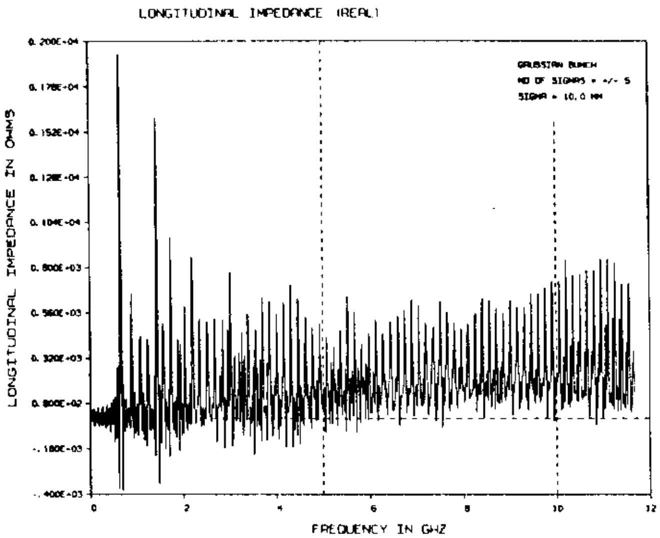

Fig. 3. Re[Z_L] of the first conical section.

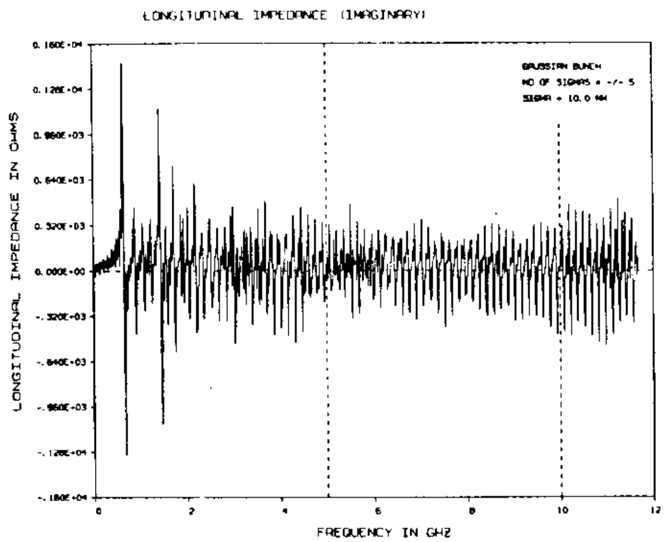

Fig. 4. Im[Z_L] of the first conical section.

TABLE 1

Mode	Freq (GHz)	Z_{sh}/Q (Ω)	Q
TM0-EE-1	0.65	45.5	5668
TM0-EE-2	0.89	13.0	7590
TM0-EE-3	1.07	8.3	7825
TM0-EE-4	1.24	5.7	7880
TM0-EE-5	1.40	0.9	7609
TM0-EE-6	1.44	17.7	7442
TM0-EE-7	1.57	6.2	8023
TM0-EE-8	1.71	0.3	9058
TM0-EE-9	1.73	8.5	9183

*Operated by the Universities Reseach Association, under contract with the U.S. Department of Energy.

The first conical section has a length of ℓ_o = 99 cm. The radius increases from b_{min} = 2 cm to b_{max} = 20 cm. The radius of the side-pipe is b_{min} = 2 cm so that it has a TM cutoff frequency of 5.74 GHz for the monopole mode and 9.14 GHz for the dipole mode. The code TBCI gives a longitudinal wake field shown in Fig. 2 and the longitudinal impedance in Figs. 3 and 4. The code URMEL is able to compute the first 9 modes with the field configurations shown in Fig. 5 and the impedances in Table 1.

We see that these modes be understood by approximating the conical cavity by a cylindrical one with resonance frequencies described by

$$f_{mnp} = \frac{c}{2\pi}\left[\left(\frac{x_{mn}}{b}\right)^2 + \left(\frac{p\pi}{\ell}\right)^2\right]^{1/2}, \qquad (1)$$

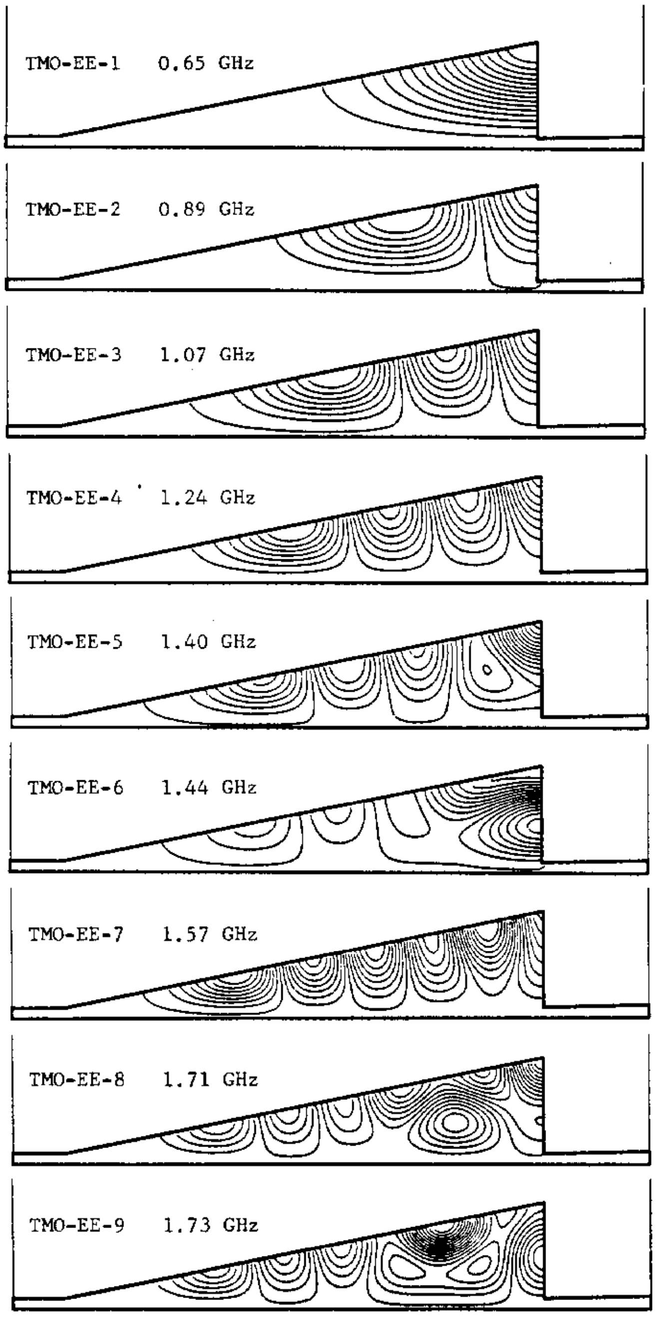

Fig. 5. The first nine monopole resonant modes showing the field distributions. The mode classification is the same as in Table I.

where m = 0 denoting monopole mode, x_{mn} is the n^{th} zero of the Bessel function of order m, p = 1, 2, 3, ..., and c is the velocity of light. Since we are dealing with a conical cavity rather than a cylindrical one, b has to be chosen somewhere between b_{min} and b_{max} while ℓ is about 1/2 to 2/3 of ℓ_o. The variation of Z_{sh}/Q is due to transit-time effect. Mode TMO-EE-5 is too weak and is not seen in the TBCI output in Fig. 3. We find in the wake potential a sharp pike every ~2 m alternating in sign. This is due to the signal bouncing back and forth inside the cavity and results in a series of resonances of constant area separated by 0.15 GHz near and above cutoff.

At low frequencies, Fig. 4 gives $\mathrm{Im}(Z_L/n)$ ~ 0.00073 Ω. This is due to the low-frequency magnetic field trapped in the corner of the cavity near the step which has an inductive impedance of

$$\mathrm{Im}\left(\frac{Z_L}{n}\right) = Z_o\frac{g}{2\pi R}\ln\frac{b_{max}}{b_{min}}, \qquad (2)$$

where Z_o is the free-space impedance, $2\pi R$ = 82.944 km is the circumference of the SSC main ring, g ~ $(b_2 - b_1)/2$ is the length inside the cavity where magnetic field can be trapped. This formula yields 0.00094 Ω comparable to the result of TBCI.

TRANSVERSE IMPEDANCE OF ONE CONICAL CAVITY

The TBCI results for the transverse mode are shown in Figs. 6 to 8. Eleven resonance modes can be computed by URMEL with results listed in Table 2. However, only a few strong modes can be seen in the TBCI plots. In the dipole case, electric and magnetic fields are present in all directions. The modes are therefore cannot be separated into TM or TE modes and, as a result, they cannot be understood so easily as the monopole case by an equation similar to Eq. (1).

TABLE 2

Mode	Freq (GHz)	Z_{sh}/Q (Ω/m)	Q
1-EE-1	0.65	1.5	7608
1-EE-2	0.84	2.7	8063
1-EE-3	1.00	104.3	7231
1-EE-4	1.02	133.7	7609
1-EE-5	1.17	1.1	8802
1-EE-6	1.27	52.5	9417
1-EE-7	1.33	1.7	9152
1-EE-8	1.47	21.7	9555
1-EE-9	1.49	7.2	9770
1-EE-10	1.56	0.2	16790
1-EE-11	1.64	2.4	9228

Again, because of trapped magnetic fields at the corner of the cavity, there is a contribution to the inductive transverse impedance, which is given, at low frequencies, by

$$\mathrm{Im}(Z_T) = \int_{-\infty}^{+\infty} W_T(z)\,dz/c, \qquad (3)$$

From Fig. 6, we see that the transverse wake potential, W_T, although oscillating, is well above zero. So, a much longer wake is necessary to compute the integral accurately. However, TBCI is not tailored for long wake. In fact, the result diverges when the wake is too long. Fortunately, since this contribution comes from space charge, it can be estimated using the magnetic part of the space-charge impedance; i.e.,

$$\mathrm{Im}(Z_T) = Z_o\frac{g}{2\pi}\left[1/b_{min}^2 - 1/b_{max}^2\right], \qquad (4)$$

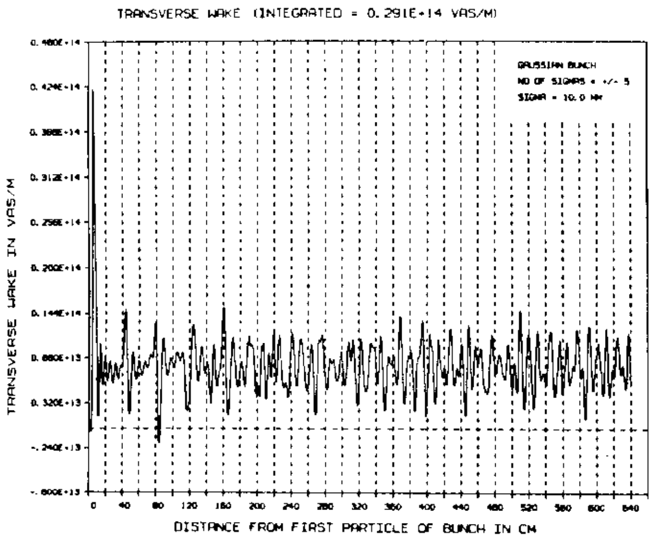

Fig. 6. Transverse wake of the first conical section.

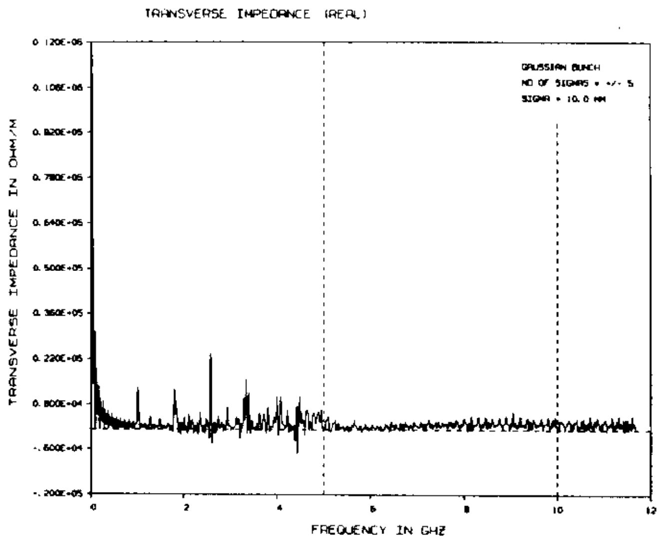

Fig. 7. Re$[Z_T]$ of the first conical section.

where, as in Eq. (1), g is the effective length of the cavity where very low frequency magnetic field can be trapped. Taking $g = (b_{max}-b_{min})/2$, we get ~0.013 MΩ/m.

TOTAL IMPEDANCES

The other three conical cavity downstream will

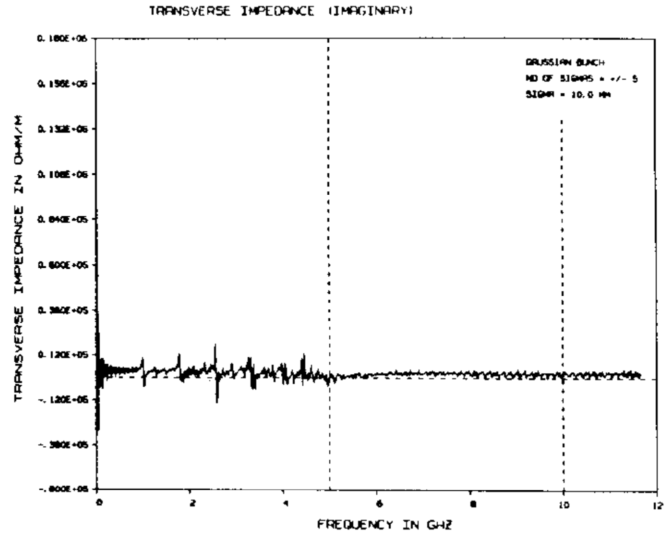

Fig. 8. Im$[Z_T]$ of the first conical section.

have similar resonances. However, they are of lengths 19 m, 80 m, and 100 m. The transit-time effect is at least inversely proportional to the length of transit. Therefore, the resonances of these latter long conical cavities should be negligible. We only need to worry the step contributions at low frequencies. Using Eqs. (1) and (4), the estimations are $\mathrm{Im}(Z_L/n)$ ~ 0.0026, 0.00029, 0.00003 Ω and $\mathrm{Im}(Z_T)$ ~ 0.028, 0.0058, 0.0011 MΩ/m for these three conical cavities. Therefore, this interaction section of the of the beam pipe will contribute in total, at low frequencies, $\mathrm{Im}(Z_L/n)$ ~0.0037 Ω and $\mathrm{Im}(Z_T)$ ~ 0.048 MΩ/m. At high frequencies, the contribution is essentially the resonances of the first conical cavity given by Figs. 3 and 7.

The extra impedances at low frequencies are very much lower than the total impedances of the whole SSC ring[2] so nothing needs to be worried. However, some of the sharp resonances have magnitudes comparable to those assumed in the RF cavities[2]. Therefore, they are capable to drive coupled-bunch instabilities unless the proposed dampers are strong enough to eliminate their effects.

REFERENCES

1. K. Foley and P. Schlein, 'A Forward Tevatron Detector for the SSC', presented at the 1986 Summer Study on the Physics of the Superconducting Super Collider, Snowmass, Colorado, June 23-July 11, 1986.
2. Conceptual Design of the Superconducting Super Collider, Edited by J. D. Jackson, Central Design Group, 1986, Section 4.5.